

Amphibians of Santa Teresa, Brazil: the hotspot further evaluated

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Abstract

A checklist of the amphibians of Santa Teresa municipality, in southeastern Brazil is presented based on fieldwork, examination of specimens in collections, and a literature review. This new amphibian list of Santa Teresa includes 108 species, of which 106 (~98%) belong to Anura and two (~2%) to Gymnophiona. Hylidae was the most represented family with 47 species (43%). Compared to the previous amphibian lists for Santa Teresa, 14 species were added, 17 previously reported species were removed, and 13 species were re-identified based on recent taxonomic rearrangements. Of the 14 species added, 11 (79%) were first recorded during our fieldwork and specimen examination. It is also the first list of caecilians for Santa Teresa. This list suggests that Santa Teresa has 0.16 species per km² (i.e., 108 species/683 km²), one of the highest densities of amphibian species in the world at a regional scale. This richness represents 78% of the

136 anurans from Espírito Santo state and 10% of the 1,080 amphibians from Brazil. We highlight the need for long-term monitoring to understand population trends and develop effective conservation plans to safeguard this remarkable amphibian richness.

Keywords

Anura, Atlantic Forest, Caecilians, Diversity, Espírito Santo, Inventory

Introduction

Species checklists provide a scientific value to areas by identifying the richness that is threatened given anthropogenic actions. The Brazilian Amphibian Conservation Action plan recognizes that species lists are a scientific priority for many areas across Brazil (Verdade et al. 2012). For instance, Brazil's Atlantic Forest is one of the most threatened global biodiversity hotspots and remains under-sampled given the high number of new species recently described (Lourenço-de-Moraes et al. 2014, Ferreira et al. 2015, Marciano-Jr et al. 2017). The Atlantic Forest has currently 12% of its historical range, which has resulted in the replacement of continuous forest to small remnants surrounded by human settlements, pastures, plantations, and roads (Ribeiro et al. 2009, Tabarelli et al. 2010). Thus, compiling data regarding the biodiversity of this tropical forest is a conservation priority, especially because several studies have detected changes and declines of some species (Heyer et al. 1988, Weygoldt 1989, Carvalho et al. 2017).

The Atlantic Forest harbors 625 anuran species and 14 caecilians (Rossa-Feres et al. 2017). The state of Espírito Santo, southeastern Brazil harbors 136 (22%) species listed for Atlantic Forest. The state's most sampled area is the municipality of Santa Teresa, which comprises high functional and phylogenetic diversity of amphibians (Almeida et al. 2011, Campos et al. 2017, Lourenço-de-Moraes et al. 2019). There are conflicting reports regarding the species composition and richness in this area. The first species list for Santa Teresa recorded 102 anuran species (Rödder et al. 2007). However, the state list of anurans mentioned 92 species for Santa Teresa (Almeida et al. 2011). In recent years, new species have been described for Santa Teresa (e.g., Lourenço-de-Moraes et al. 2014, Ferreira et al. 2015, Taucce et al. 2018), some species have been reported for the first time in the area (Simon and Peres 2012), and there have been many taxonomic changes (e.g., Pimenta et al. 2014, Walker et al. 2016), indicating the need to update the species list of this anuran diversity hotspot.

Santa Teresa is also a hotspot for several other taxa, such as plants (Thomaz and Monteiro 1997), birds (Simon 2000), butterflies (Brown and Freitas 2000), and small mammals (Passamani et al. 2000). Due to its remarkable biological importance, it is essential to keep the species lists updated. Here, we present an updated species list of the amphibians for Santa Teresa based on many years of fieldwork, examination of specimens from scientific collections, and literature review.

Materials and methods

Study area

The municipality of Santa Teresa has 683 km² and is located in the mountainous region (altitude range: ~120–1099 m a.s.l.) of Espírito Santo state, southeastern Brazil (19°56'14"S, 40°35'52"W; Figure 1). Santa Teresa encompasses the southern portion of Bahia Coastal Forests ecoregion, and northern portion of Serra do Mar ecoregion in the Atlantic Forest (Olson et al. 2001, Scaramuzza et al. 2011, Campos and Lourenço-de-Moraes 2017, Silva et al. 2018).

The predominant vegetation types are montane and sub-montane rainforests (Rizzini 1979), characterized by non-deciduous trees with lead buds without protection against drought (Brasil 1983). Santa Teresa was mostly forested until the arrival of European settlers in 1874. Currently, the municipality has 42% of its original forest cover inside and surrounding three protected areas: the Reserva Biológica Augusto Ruschi (3,598 ha), the Estação Biológica de Santa Lúcia (440 ha), and the Parque Natural de São Lourenço (22 ha) (SOS Mata Atlântica and Inpe 2013). Outside these protected areas, forest remnants are in private properties and mostly restricted to hilltops while the valleys are dominated by different types of human-modified matrix (e.g., coffee plantations, *Eucalyptus* spp. plantations, abandoned pastures, and settlements; Ferreira et al. 2016).

The climate of Santa Teresa is classified as oceanic climate without dry season and with temperate summer (Cfb) according to Köppen classification (Alvares et al. 2013). Mean annual precipitation is 1,868 mm with highest rainfall in November and lowest in June, when the mean rainfall is less than 60 mm (Mendes and Padovan 2000). Mean annual temperature is 20 °C (range: 14.3–26.2 °C, Thomaz and Monteiro 1997).

Data sampling

The species list presented in this study has been compiled in part using field surveys conducted by the authors from 2006 to 2019, and also through the evaluation of specimens in zoological collections (see Appendix I) and a literature review.

During field surveys, we conducted intensive sampling across Santa Teresa using audio and visual searches inside bromeliads, in the leaf litter, and in water bodies (see Dodd 2010). We released easily identified and extensively vouchered (> 30 specimens) species but took those species with more complex identification back to laboratory. To do this, we kept amphibians in moist plastic tubes or plastic bags to prevent dehydration. Some specimens were euthanized by ventral application of 7.5% to 20% benzocaine, preserved using 10% formalin and then transferred to 70% ethanol (American and Veterinary Medical Association 2013, CEBEA/CFMV 2013).

We also reviewed the literature and compiled records of amphibians for Santa Teresa. In addition, we examined specimens deposited in the following institutions:

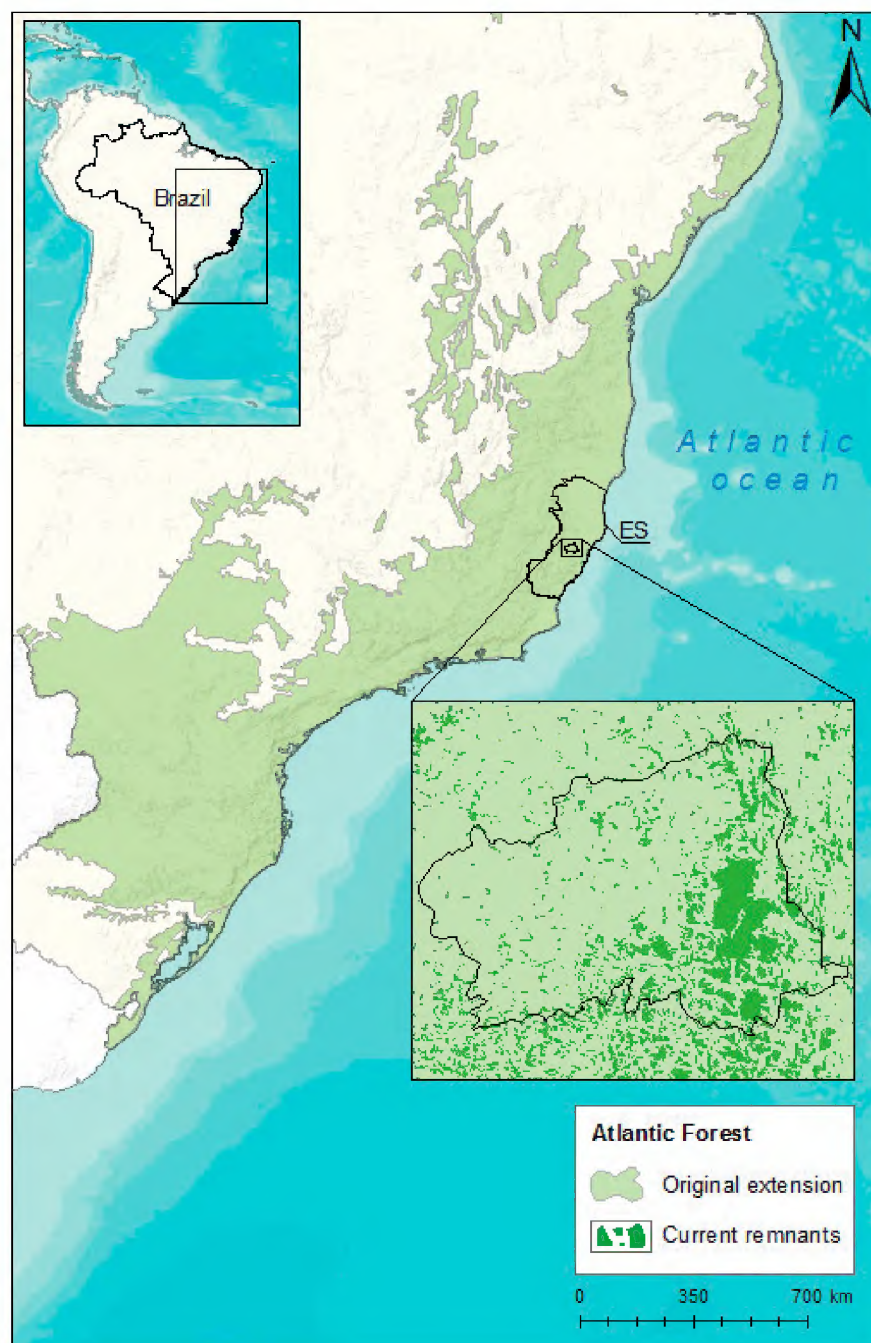


Figure 1. Location of the municipality of Santa Teresa, southeastern Brazil. Forest remnants from SOS Mata Atlântica (2014).

Coleção de Anfíbios Célio F. B. Haddad (CFBH), Universidade Estadual Paulista (UNESP); Museu de Biologia Mello Leitão (MBML), Instituto Nacional da Mata Atlântica (INMA); Universidade Federal de Minas Gerais (UFMG); Museu Nacional, Universidade Federal do Rio de Janeiro (MNRJ); Museu de Zoologia Prof. Adão José Cardoso (ZUEC), Universidade Estadual de Campinas (UNICAMP); Museu de Zoologia, Universidade de São Paulo (MZUSP); and Smithsonian National Museum of Natural History (USNM) (see Appendix I). We followed Frost (2019) for taxonomic arrangements.

Results

We recorded 108 amphibian species for Santa Teresa, of which 106 (98%) belong to Anura (16 families and 41 genera) and two (2%) to Gymnophiona (one family and one genus) (Table 1; Figure 2, 3, 4, 5, 6, 7). The most represented families were Hylidae

Table 1. Amphibian species of Santa Teresa municipality, Espírito Santo state, Southeastern Brazil. An asterisk * indicates a taxonomic change.

Species by Family	Type locality	Our study	Almeida et al. 2011	Rödder et al. 2007
AROMOBATIDAE				
<i>Allobates capixaba</i> (Lutz, 1925)		X	X	X*
BRACHYCEPHALIDAE				
<i>Brachycephalus alipioi</i> Pombal & Gasparini, 2006		X	X	–
<i>Brachycephalus</i> aff. <i>didactylus</i>		X	–	–
<i>Ischnocnema abdita</i> Canedo & Pimenta, 2010	X	X	X	–
<i>Ischnocnema colibri</i> Taucce, Canedo, Parreiras, Drummond, Nogueira-Costa & Haddad, 2018	X	X	–	–
<i>Ischnocnema epipeda</i> (Heyer, 1984)	X	X	X	X
<i>Ischnocnema</i> aff. <i>guentheri</i>		X	X*	X*
<i>Ischnocnema</i> cf. <i>nasuta</i> (Lutz, 1925)		X	X*	X*
<i>Ischnocnema oea</i> (Heyer, 1984)	X	X	X	X
<i>Ischnocnema</i> aff. <i>parva</i> sp. 1		X	X*	X*
<i>Ischnocnema</i> aff. <i>parva</i> sp. 2		X	–	–
<i>Ischnocnema verrucosa</i> Reinhardt & Lütken, 1862		X	X	X
BUFONIDAE				
<i>Dendrobrynis carvalhoi</i> Izecksohn, 1994	X	X	X	X
<i>Rhinella crucifer</i> (Wied-Neuwied, 1821)		X	X	X
<i>Rhinella granulosa</i> (Spix, 1824)		X	X	X
<i>Rhinella diptycha</i> (Cope, 1862)		X	X	X
CENTROLENIDAE				
<i>Vitreorana</i> aff. <i>eurygnatha</i>		X	X*	X*
<i>Vitreorana uranoscopa</i> (Müller, 1924)		X	X	X
CERATOPHRYIDAE				
<i>Ceratophrys aurita</i> (Raddi, 1823)		X	X	X*
CRAUGASTORIDAE				
<i>Euparkerella tridactyla</i> Izecksohn, 1988	X	X	X	X
<i>Haddadus binotatus</i> (Spix, 1824)		X	X	X
CYCLORAMPHIDAE				
<i>Cycloramphus fuliginosus</i> Tschudi, 1838		X	X	X
<i>Thoropa</i> aff. <i>lutzi</i>		X	X*	–
<i>Thoropa miliaris</i> (Spix, 1824)		X	X	X
<i>Thoropa petropolitana</i> (Wandolleck, 1907)		X	X	–
<i>Zachaenus carvalhoi</i> Izecksohn, 1983	X	X	X	X
ELEUTHERODACTYLIDAE				
<i>Adelophryne glandulata</i> Lourenço-de-Moraes, Ferreira, Fouquet & Bastos, 2014	X	X	X*	–
HEMIPHRACTIDAE				
<i>Fritziana</i> aff. <i>fissilis</i>		X	X*	X*
<i>Fritziana tonimi</i> Walker, Gasparini, Haddad, 2016	X	X	X*	X*
<i>Gastrotheca albolineata</i> (Lutz & Lutz, 1939)		X	X	–
<i>Gastrotheca ernestoi</i> Miranda-Ribeiro, 1920		X	–	–
<i>Gastrotheca megacephala</i> Izecksohn, Carvalho-e-Silva & Peixoto, 2009		X	–	–

Species by Family	Type locality	Our study	Almeida et al. 2011	Rödger et al. 2007
HYLIDAE				
<i>Aparasphenodon bruno</i> Miranda-Ribeiro, 1920		X	–	X
<i>Aplastodiscus cavicola</i> (Cruz & Peixoto, 1985)	X	X	X	X
<i>Aplastodiscus</i> aff. <i>eugenioi</i>		X	–	–
<i>Aplastodiscus weygoltdi</i> (Cruz & Peixoto, 1987)	X	X	X	X
<i>Boana albomarginata</i> (Spix, 1824)		X	X	X
<i>Boana albopunctata</i> (Spix, 1824)		X	X	X
<i>Boana crepitans</i> (Wied-Neuwied, 1824)		X	X	X
<i>Boana faber</i> (Wied-Neuwied, 1821)		X	X	X
<i>Boana pardalis</i> (Spix, 1824)		X	X	X
<i>Boana polytaenia</i> (Cope, 1870)		X	X	–
<i>Boana semilineata</i> (Spix, 1824)		X	X	X
<i>Bokermannohyla caramaschii</i> (Napoli, 2005)	X	X	X	X
<i>Dendropsophus berthallutzae</i> (Bokermann, 1962)		X	X	X
<i>Dendropsophus bipunctatus</i> (Spix, 1824)		X	X	X
<i>Dendropsophus branneri</i> (Cochran, 1948)		X	X	X
<i>Dendropsophus bromeliaceus</i> Ferreira, Faivovich, Beard & Pombal, 2015	X	X	–	–
<i>Dendropsophus decipiens</i> (Lutz, 1925)		X	X	X
<i>Dendropsophus elegans</i> (Wied-Neuwied, 1824)		X	X	X
<i>Dendropsophus giesleri</i> (Mertens, 1950)		X	X	X
<i>Dendropsophus haddadi</i> (Bastos & Pombal, 1996)		X	X	X
<i>Dendropsophus microps</i> (Peters, 1872)		X	X	X
<i>Dendropsophus minutus</i> (Peters, 1872)		X	X	X
<i>Dendropsophus ruschii</i> (Weygoldt & Peixoto, 1987)		X	X	X
<i>Dendropsophus seniculus</i> (Cope, 1868)		X	X	X
<i>Itapotihyla langsdorffii</i> (Duméril & Bibron, 1841)		X	X	X
<i>Oloolygon arduous</i> (Peixoto, 2002)	X	X	X	X
<i>Oloolygon argyreornata</i> (Miranda-Ribeiro, 1926)		X	X	X
<i>Oloolygon</i> cf. <i>flavoguttata</i> (Lutz & Lutz, 1939)		X	–	–
<i>Oloolygon</i> aff. <i>heyeri</i>		X	–	–
<i>Oloolygon heyeri</i> Peixoto & Weygoldt, 1986	X	X	X	X
<i>Oloolygon kautskyi</i> Carvalho-e-Silva & Peixoto, 1991		X	X	X
<i>Phasmahyla exilis</i> (Cruz, 1980)	X	X	X	X
<i>Phrynomedusa marginata</i> (Izecksohn & Cruz, 1976)	X	X	X	X
<i>Phyllodytes kautskyi</i> Peixoto & Cruz, 1988		X	–	–
<i>Phyllodytes luteolus</i> (Wied-Neuwied, 1824)		X	X	X
<i>Phyllodytes</i> aff. <i>luteolus</i>		X	–	–
<i>Phyllomedusa burmeisteri</i> Boulenger, 1882		X	X	X
<i>Pithecopus</i> aff. <i>rohdei</i>		X	X*	X*
<i>Scinax alter</i> (Lutz, 1973)		X	X	X
<i>Scinax cuspidatus</i> (Lutz, 1925)		X	X	X
<i>Scinax eurydice</i> (Bokermann, 1968)		X	X	X*
<i>Scinax fuscovarius</i> (Lutz, 1925)		X	X	X
<i>Scinax hayii</i> (Barbour, 1909)		X	X	X*
<i>Scinax</i> aff. <i>perereca</i>		X	–	–
<i>Scinax</i> cf. <i>x-signatus</i> (Spix, 1824)		X	X	X

Species by Family	Type locality	Our study	Almeida et al. 2011	Rödder et al. 2007
<i>Trachycephalus mesophaeus</i> (Hensel, 1867)		X	X	X
<i>Trachycephalus nigromaculatus</i> Tschudi, 1838		X	X	X
HYLODIDAE				
<i>Crossodactylus</i> aff. <i>gaudichaudii</i>		X	X	X*
<i>Crossodactylus timbuhy</i> Pimenta, Cruz & Caramaschi, 2014	X	X	X*	X*
<i>Hylodes</i> cf. <i>babax</i> Heyer, 1982		X	X*	X*
<i>Hylodes lateristrigatus</i> (Baumann, 1912)		X	X	X
<i>Megaelosia apuana</i> Pombal, Prado & Canedo, 2003		X	X	X*
LEPTODACTYLIDAE				
<i>Crossodactylodes bokermanni</i> Peixoto, 1983	X	X	X	X
<i>Crossodactylodes izecksohni</i> Peixoto, 1983	X	X	X	X
<i>Leptodactylus cupreus</i> Caramaschi, Feio & São Pedro, 2008		X	X	–
<i>Leptodactylus fuscus</i> (Schneider, 1799)		X	X	X
<i>Leptodactylus</i> aff. <i>latrans</i> (Steffen, 1815)		X	X*	X*
<i>Leptodactylus</i> aff. <i>spixi</i>		X	X*	X*
<i>Physalaemus crombiei</i> Heyer & Wolf, 1989	X	X	X	X
<i>Physalaemus cuvieri</i> Fitzinger, 1826		X	X	X
<i>Physalaemus maculiventris</i> (Lutz, 1925)		X	X	–
<i>Physalaemus</i> cf. <i>olfersii</i> (Lichtenstein & Martens, 1856)		X	X*	X*
MICROHYLIDAE				
<i>Chiasmocleis capixaba</i> Cruz, Caramaschi & Izecksohn, 1997		X	–	–
<i>Chiasmocleis schubarti</i> Bokermann, 1952		X	–	X
<i>Myersiella microps</i> (Duméril & Bibron, 1841)		X	X	X
ODONTOPHRYNIDAE				
<i>Macrogenioglottus alipioi</i> Carvalho, 1946		X	X	X
<i>Proceratophrys boiei</i> (Wied-Neuwied, 1824)		X	X	X
<i>Proceratophrys laticeps</i> Izecksohn & Peixoto, 1981		X	X	X
<i>Proceratophrys moehringi</i> Weygoldt & Peixoto, 1985	X	X	X	X
<i>Proceratophrys paviotii</i> Cruz, Prado & Izecksohn, 2005	X	X	X	X
<i>Proceratophrys phyllostomus</i> Izecksohn, Cruz & Peixoto, 1999		X	X	X
<i>Proceratophrys schirchi</i> (Miranda-Ribeiro, 1937)		X	X	X
PIPIDAE				
<i>Pipa</i> aff. <i>carvalhoi</i>		X	X*	X*
RANIDAE				
<i>Lithobates catesbeianus</i> (Shaw, 1802)		X	–	–
SIPHONOPIDAE				
<i>Siphonops annulatus</i> (Mikan, 1822)		X	–	–
<i>Siphonops hardyi</i> Boulenger, 1888		X	–	–

with 47 species (43%), Brachycephalidae with 11 species (10%), and Leptodactylidae with 10 species (9%). Santa Teresa is currently the type locality for 23 species (20%) (Table 1). So far, four species (3%) are only found in Santa Teresa such as *Crossodactylodes izecksohni*, *Crossodactylus timbuhy*, *Ischnocnema colibri* and *Ischnocnema epipeda*. The species density of Santa Teresa is 0.16 species per km² (i.e., 108 species/683 km²).

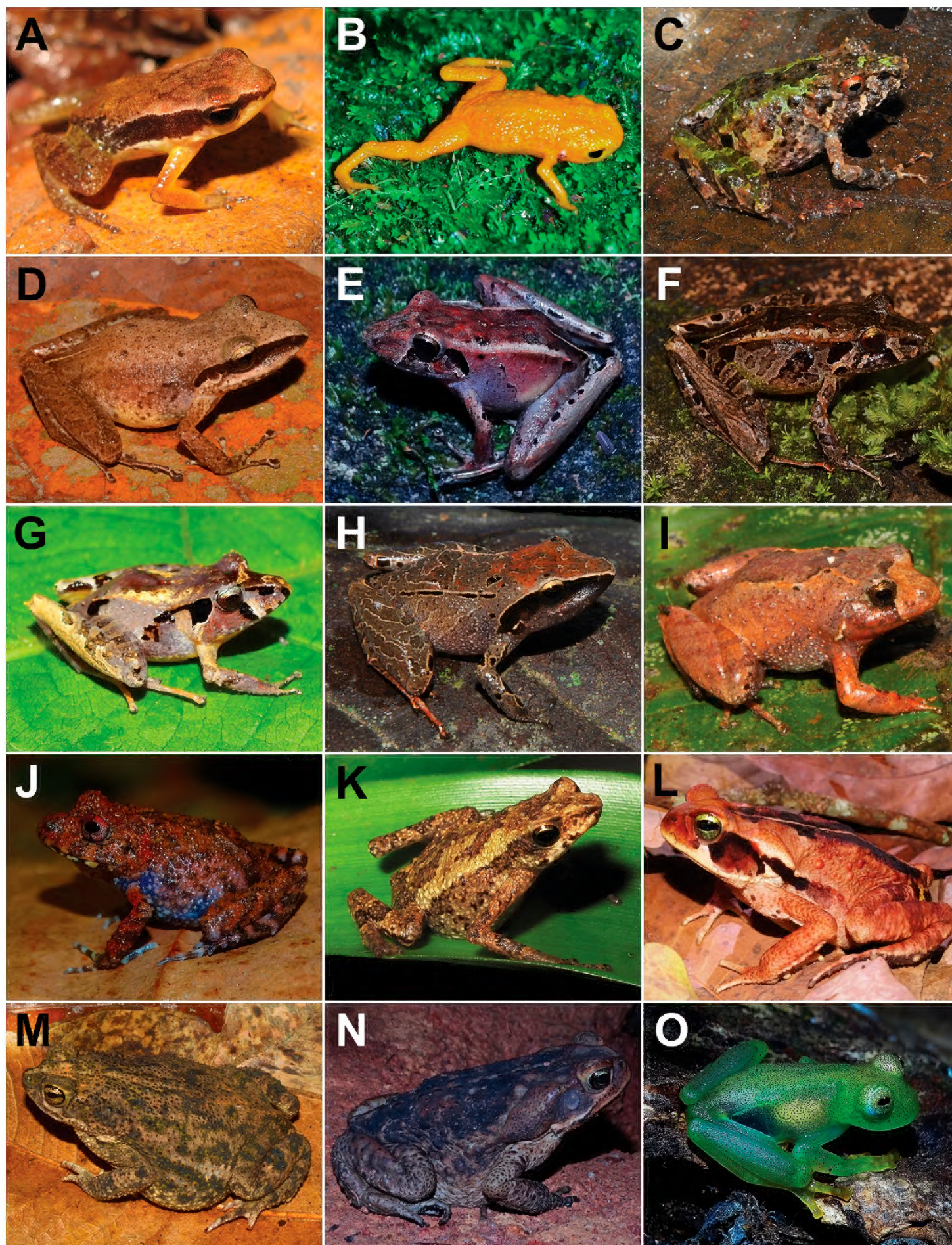


Figure 2. Amphibians from Santa Teresa: **A** *Allobates capixaba* **B** *Brachycephalus alipioi* **C** *Ischnocnema abdita* **D** *Ischnocnema colibri* **E** *Ischnocnema* cf. *nasuta* **F** *Ischnocnema* aff. *guentheri* **G** *Ischnocnema oea* **H** *Ischnocnema* gr. *parva* sp. new 1 **I** *Ischnocnema* gr. *parva* sp. new 2 **J** *Ischnocnema verrucosa* **K** *Dendrophryniscus carvalhoi* **L** *Rhinella crucifer* **M** *Rhinella granulosa* **N** *Rhinella diptycha* **O** *Vitreorana* aff. *eurygnatha*. Photographs by JFR Tonini (**A**), CN Fraga (**B**), RB Ferreira (**C**, **D**, **H**, **I**, **K**), AT Mônico (**E**, **G**, **J**, **K**, **L**, **M**, **N**, **O**), T Silva-Soares (**F**).

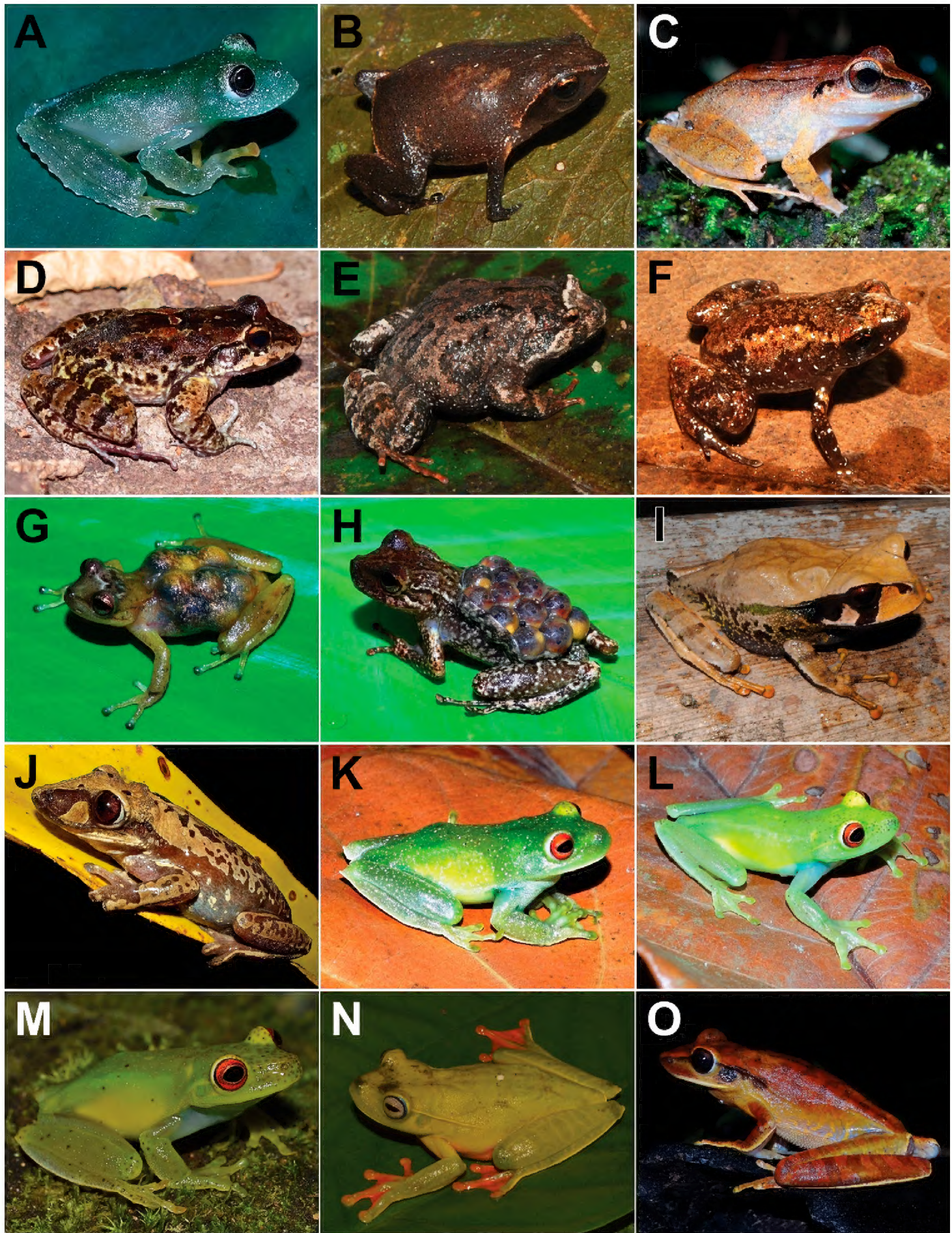


Figure 3. Amphibians from Santa Teresa: **A** *Vitreorana uranoscopa* **B** *Euparkerella tridactyla* **C** *Haddadus binotatus* **D** *Thoropa miliaris* **E** *Zachaeus carvalhoi* **F** *Adelophryne glandulata* **G** *Fritziana* aff. *fissilis* **H** *Fritziana tonimi* **I** *Gastrotheca megacephala* **J** *Aparasphenodon bruno* **K** *Aplastodiscus cavicola* **L** *Aplastodiscus* aff. *eugenioi* **M** *Aplastodiscus weygoldti* **N** *Boana albomarginata* **O** *Boana albopunctata*. Photographs by AT Mônico (**A, C, D, G, H, K, L, O**), RB Ferreira (**B, E, F, I, N**), C Zocca (**J**), T Silva-Soares (**M**).

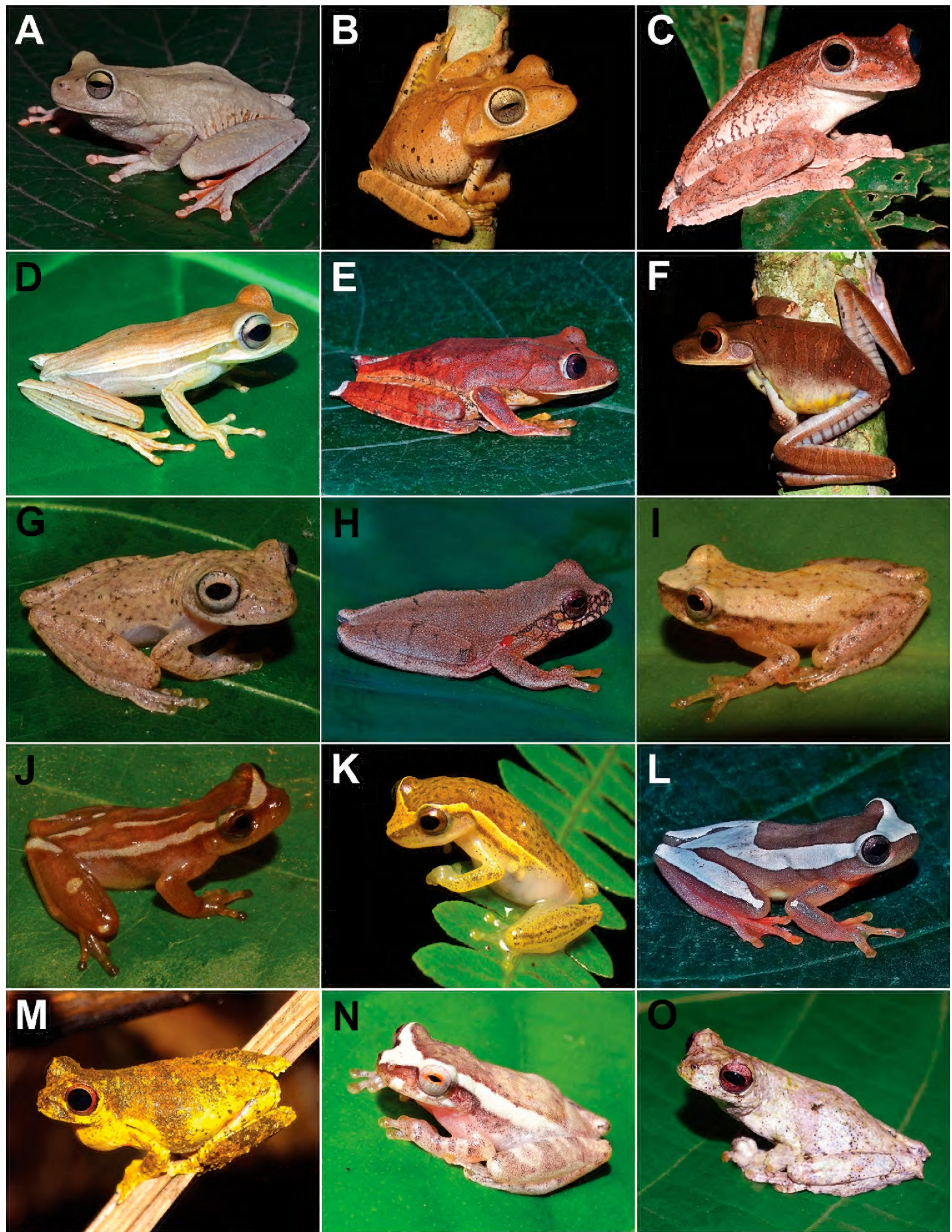


Figure 4. Amphibians from Santa Teresa: **A** *Boana crepitans* **B** *Boana faber* **C** *Boana pardalis* **D** *Boana polytaenia* **E** *Boana semilineata* **F** *Bokermannohyla caramaschii* **G** *Dendropsophus berthaltutzae* **H** *Dendropsophus bipunctatus* **I** *Dendropsophus branneri* **J** *Dendropsophus bromeliaceus* **K** *Dendropsophus decipiens* **L** *Dendropsophus elegans* **M** *Dendropsophus giesleri* **N** *Dendropsophus haddadi* **O** *Dendropsophus microps*. Photographs by AT Mônico (**A, C, D, E, F, H, L, M, N, O**), RB Ferreira (**B, G, I, J**), ET Silva (**K**).

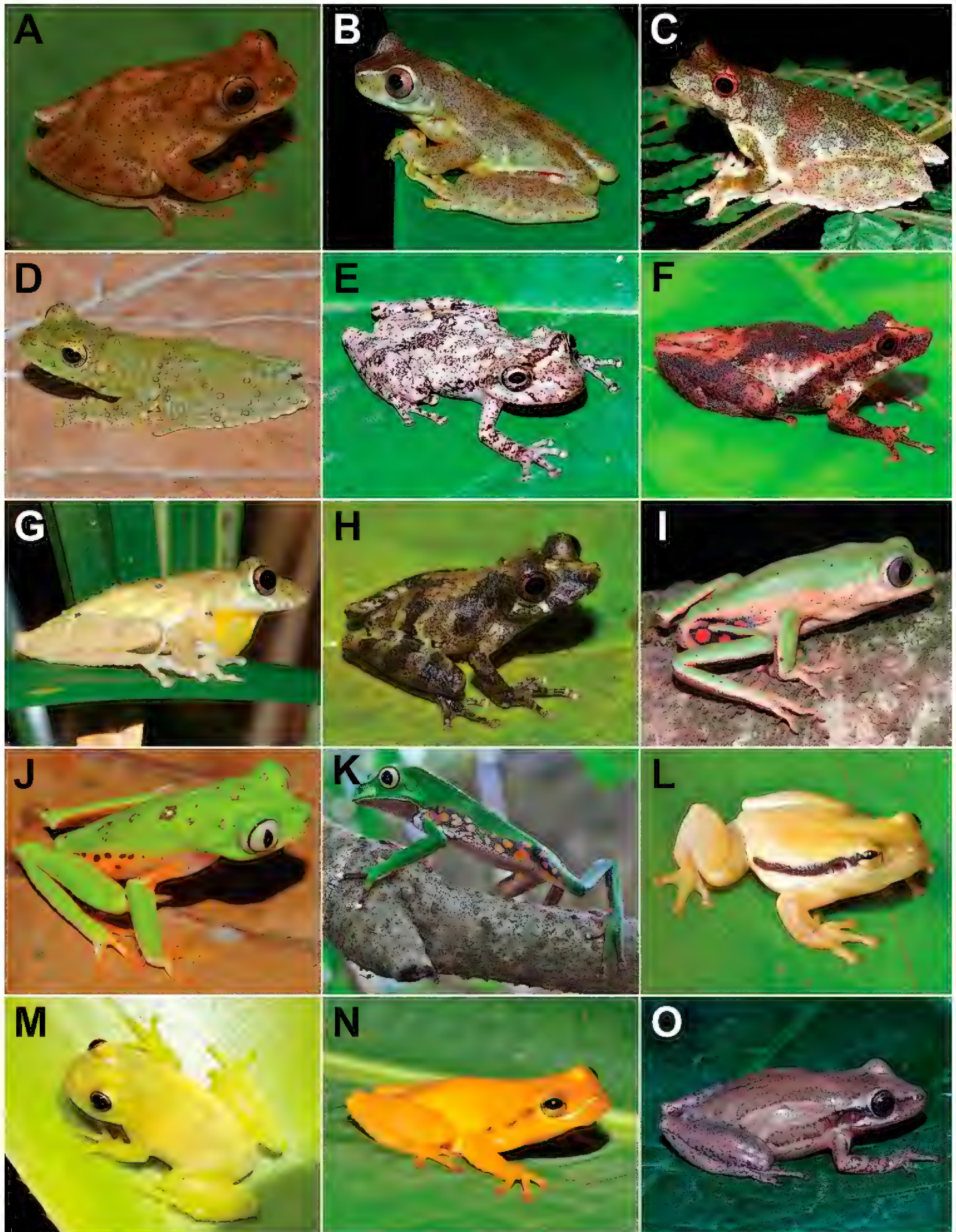


Figure 5. Amphibians from Santa Teresa: **A** *Dendropsophus minutus* **B** *Dendropsophus ruschii* **C** *Dendropsophus seniculus* **D** *Itapotihyla langsdorffii* **E** *Ololygon arduous* **F** *Ololygon argyreornata* **G** *Ololygon heyeri* **H** *Ololygon kautskyi* **I** *Pithecopus* aff. *rohdei* **J** *Phasmahyla exilis* **K** *Phyllomedusa burmeisteri* **L** *Phyllodytes kautskyi* **M** *Phyllodytes luteolus* **N** *Phyllodytes* aff. *luteolus* **O** *Scinax alter*. Photographs by RB Ferreira (**A, D, J**), AT Mônico (**B, C, E, F, G, I, K, N, O**), T Silva-Soares (**H**), CZ Zocca (**L, M**).

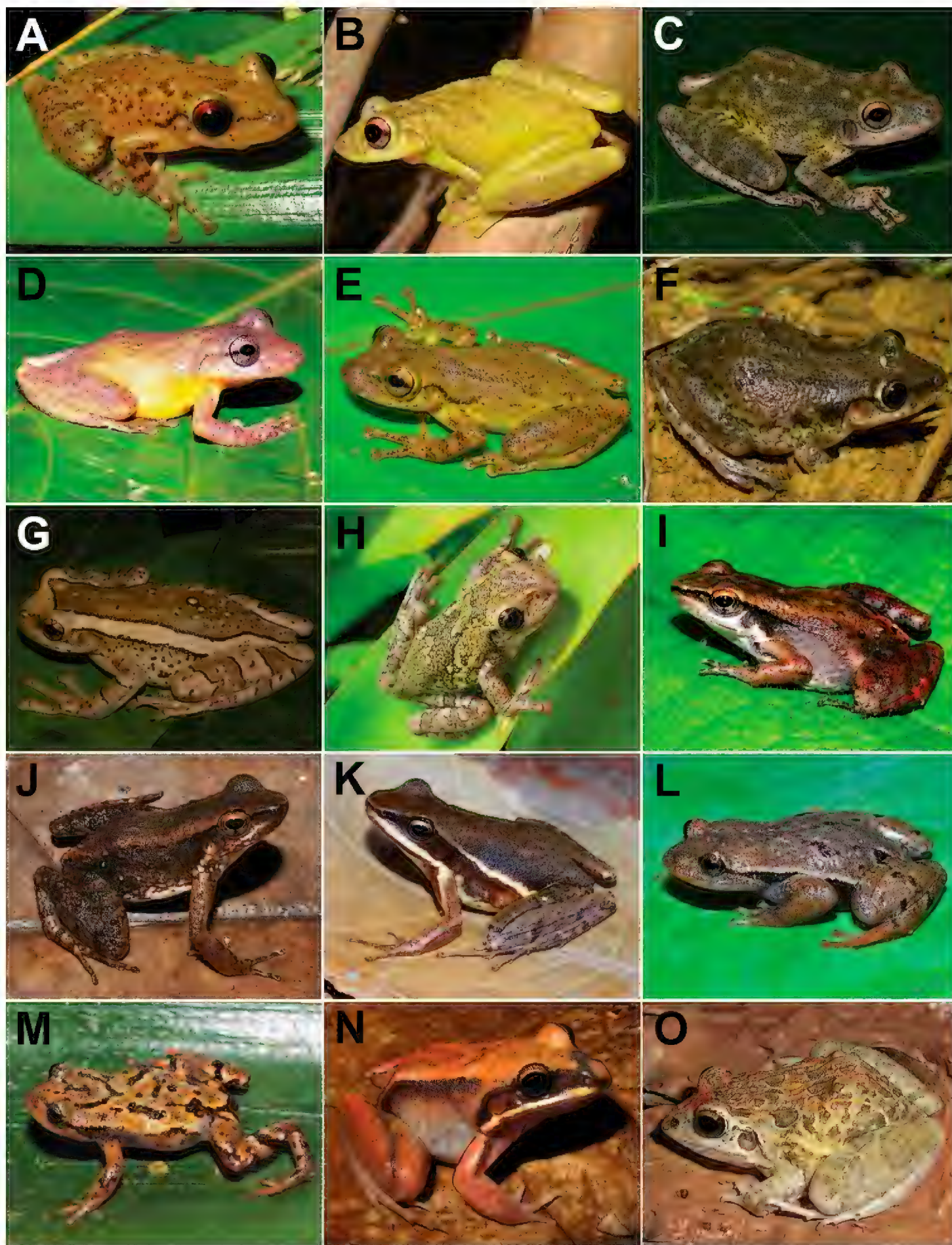


Figure 6. Amphibians from Santa Teresa: **A** *Scinax cuspidatus* **B** *Scinax eurydice* **C** *Scinax fuscovarius* **D** *Scinax hayii* **E** *Scinax* aff. *perereca* **F** *Scinax* cf. *x-signatus* **G** *Trachycephalus mesophaeus* **H** *Trachycephalus nigromaculatus* **I** *Crossodactylus* aff. *gaudichaudii* **J** *Crossodactylus timbuhy* **K** *Hylodes lateristrigatus* **L** *Crossodactylodes bokermanni* **M** *Crossodactylodes izecksohni* **N** *Leptodactylus cupreus* **O** *Leptodactylus fuscus*. Photographs by ET Silva (**A, E, F**), CZ Zocca (**B, O**), T Silva-Soares (**C**), AT Mônico (**D, I, K, L**), RB Ferreira (**G, H, J, M**), JFR Tonini (**N**).



Figure 7. Amphibians from Santa Teresa: **A** *Leptodactylus* aff. *latrans* **B** *Leptodactylus* aff. *spixi* **C** *Physalaemus crombiei* **D** *Physalaemus cuvieri* **E** *Physalaemus maculiventris* **F** *Chiasmocleis capixaba* **G** *Chiasmocleis schubarti* **H** *Myersiella microps* **I** *Proceratophrys boiei* **J** *Proceratophrys laticeps* **K** *Proceratophrys paviotii* **L** *Proceratophrys schirchi* **M** *Pipa* aff. *carvalhoi* **N** *Siphonops annulatus* **O** *Siphonops hardyi*. Photographs by T Silva-Soares (**A, B, L, M, N**), AT Mônico (**C, D, E, G, H, J, K**), RB Ferreira (**F, I, O**).

Compared to previous anuran lists for Santa Teresa, we added 14 species, removed 17 previously reported species, and re-determined 14 species based on recent taxonomic rearrangements. Out of the 14 added species, 11 (79%) were first recorded during our fieldwork and specimen examination, two (14%) records were from the literature, and one (7%) new record was from pers. comm. (*Gastrotheca ernestoi*; MT Rodrigues, field number MTR 34695).

Fourteen species classified to morphotypes are new species, such as *Aplastodiscus* aff. *eugenioi* (M Mongin, pers. comm.), *Brachycephalus* aff. *didactylus* (TSS, in. prep.), *Crossodactylus* aff. *gaudichaudii* (R Montesinos, in. prep.), *Fritziana* aff. *fissilis* (RBF, pers. obs.), *Ischnocnema* aff. *parva* sp. 1 (CAG Cruz, in. prep.), *Ischnocnema* aff. *parva* sp. 2 (TSS, in. prep.), *Leptodactylus* aff. *spixi* (L Nascimento, in. prep.), *Ololygon* aff. *heyeri* (J Lacerda, pers. comm.), *Phyllodytes* aff. *luteolus* (ATM, in. prep.), *Pipa* aff. *carvalhoi* (PV Scherrer, in. prep.), *Pithecopus* aff. *rohdei* (D Baêta, pers. comm.), *Scinax* aff. *perereca* (TSS, pers. comm.), *Thoropa* aff. *lutzi* (CL Assis, pers. comm.), and *Vitreorana* aff. *eurygnatha* (R Pontes, in. prep.).

Discussion

The current number of 106 anuran species for Santa Teresa is remarkable, and represents 78% of the 136 species listed for Espírito Santo state (Almeida et al. 2011, Rossa-Feres et al. 2017), 10% of the 1,080 species listed for Brazil (Segalla et al. 2016), and 1.5% of the 7,068 species listed worldwide (AmphibiaWeb 2019). To date, the species density (i.e., 0.16 species per km²) is one of the highest in the world at regional scale. For instance, Yasuní National Park in Ecuador has 0.015 species per km² (i.e., 150 species/9,820 km²; Bass et al. 2010); Tambopata in southern Peru has 0.06 species per km² (i.e., 99 species/1,600 km²; Doan and Arriaga 2002); Iquitos region of northern Loreto in Peru has 0.012 species per km² (i.e., 141 species/11,310 km²; IUCN 2008, Rodríguez and Duellman 1994); and Leticia in Colombia has 0.13 species per km² (i.e., 123 species/927 km²; Lynch 2005). Several other localities across the Atlantic Forest also have remarkable amphibian richness at local scales. For example, Reserva Biológica de Paranapiacaba in Sao Paulo state has 20.5 species per km² (69 species/3.36 km²; Verdade et al. 2009); Fazenda Vista Bela in Bahia state has 7.3 species per km² (34 species/4.65 km²; Silvano and Pimenta 2003); and Reserva Particular do Patrimônio Natural Serra Bonita has 4 species per km² (80 species/20 km²; Dias et al. 2014). We acknowledge that amphibian richness per area represents just a first approximation for practical spatial comparisons and that the lack of adequate surveys in more unexplored diverse regions (e.g., Indonesia, New Guinea, and the Congo Basin) may reveal remarkable amphibian richness. So far, Brazil's Atlantic Forest and the northwest Amazon are considered the world's greatest amphibian diversity on a landscape scale (Young et al. 2004, Bass et al. 2010).

The two species of Gymnophiona (*Siphonops annulatus* and *S. hardyi*) were found during our fieldwork but have been reported previously for Santa Teresa (Caramaschi

et al. 2004, Maciel et al. 2009). The former has a wide distribution in South America from Colombia to Argentina (Frost 2018). The latter has a more restricted distribution in southeastern of Brazil (Maciel et al. 2009, Frost 2018). Caecilians are difficult to sample due to the subterranean or aquatic habits (Oommen et al. 2000, Maciel and Hoogmoed 2011). Although amphibians are dramatically declining (Stuart et al. 2004), the conservation status of caecilians is largely unknown due to the lack of information on their biology, ecology and natural history (Wilkinson and Nussbaum 1999, Oommen et al. 2000, Gower and Wilkinson 2005). It is likely more species of caecilians will be recorded in Santa Teresa if the use of sampling methods specific for these taxa is applied in the field.

Our fieldwork since 2005 in Santa Teresa has made notable contributions toward the knowledge of local amphibians. It has resulted in the description of three new species for the municipality (i.e., *Adelophryne glandulata* in Lourenço-de-Moraes, Ferreira, Fouquet, Bastos 2014, *Dendropsophus bromeliaceus* in Ferreira, Faivovich, Beard, Pombal 2015, and *Ischnocnema colibri* in Taucce, Canedo, Parreiras, Drummond, Nogueira-Costa, Haddad 2018). Furthermore, our fieldwork found individuals of 13 morphospecies that are currently under formal description (i.e., *Aplastodiscus* aff. *eugenioi*, *Brachycephalus* aff. *didactylus*, *Crossodactylus* aff. *gaudichaudii*, *Fritziana* aff. *fissilis*, *Ischnocnema* aff. *parva* sp. 1, *Ischnocnema* aff. *parva* sp. 2, *Leptodactylus* aff. *spixi*, *Ololygon* aff. *heyeri*, *Phyllodytes* aff. *luteolus*, *Pipa* aff. *carvalhoi*, *Pithecopus* aff. *rohdei*, *Scinax* aff. *perereca*, and *Vitreorana* aff. *eurygnatha*). The discovery of new species, morphospecies, and new records for Santa Teresa may be due to our sampling in remote forested areas and rocky outcrops through both visual bromeliad surveys and active leaf-litter searches (Ferreira et al. 2016).

Our species list resolved some differences between the previous species lists of Santa Teresa, which had disagreements on 11 species (e.g., Rödder et al. 2007, Almeida et al. 2011). We confirmed that *Chiasmocleis schubarti* occurs in Santa Teresa based on several individuals sampled in the Reserva Biológica Augusto Ruschi, whereas Almeida et al. (2011) challenged previous records of this species listed in Cruz et al. (1997) and Rödder et al. (2007). We also confirmed the presence of *Aparasphenodon bruno*i and *Trachycephalus nigromaculatus* reported in Santa Teresa at the buffer zone of the Parque Municipal do Goiapaba-Açu (Ramos and Gasparini 2004). Almeida et al. (2011) challenged the record of *Rhinella hoogmoedi* referring to the species as *Rhinella* gr. *margaritifera*, because the former species was not mentioned in Rödder et al. (2007). We agree with Almeida et al. (2011) regarding the exclusion of several species from Rödder et al. (2007), such as *Bokermannohyla* aff. *nanuzae* (MBML 4528 corresponds to *B. caramaschii*), *Dendrophryniscus* sp. (MBML 3841 corresponds to *D. carvalhoi*), *Ischnocnema* cf. *juipoca* (MBML 5737 corresponds to *I. abdita*), *I. lactea* (MBML 1143 corresponds to *I. abdita*), *Physalaemus aguirrei* (MBML 2803-04 correspond to *P.* cf. *olfersii*), and *Proceratophrys appendiculata* (MBML 1154 corresponds to *P. schirchii*). Rödder et al. (2007) and Almeida et al. (2011) listed *Leptodactylus natalensis* for Santa Teresa but the voucher specimens (MBML 3909-10) were misidentified and actually refer to individuals of *L.* aff. *spixi*. Rödder et al. (2007) listed *Allobates* cf. *olfersioides*

following Verdade and Rodrigues (2007) who placed *A. capixaba* as synonym of *A. olfersioides*. Studies on *Allobates* indicate *A. capixaba* is a valid taxon (e.g., Bokermann 1967; Forti et al. 2017), which agrees with Almeida et al. (2011). Fieldwork should be conducted in the vicinities of Santa Teresa to confirm the presence of *Brachycephalus alipioi*. This species has not been found in Santa Teresa since 1952 when the municipality was larger than it is today (Pombal and Gasparini 2006).

The wide elevational range of Santa Teresa (~120–1099 m a.s.l.) partially explains the high richness of amphibian species. Species typical of both Atlantic Forest lowlands (e.g., *Allobates capixaba*, *Chiasmocleis schubarti*, *C. capixaba*, *Dendropsophus bipunctatus*, *Ololygon argyreornata*) and highlands (e.g., *Aplastodiscus cavicola*, *Bokermannohyla caramaschii*, *Dendropsophus ruschii*) occur in Santa Teresa, which suggest that the elevational gradient influences species composition. The high amphibian diversity also may be related to edaphic and topographic heterogeneity, which is known to cause speciation in many Atlantic Forest species occurring in mountainous areas (Carnaval et al. 2014). The high altitude and proximity to the Atlantic Ocean favors frequent orographic rain, which contribute to the meeting the reproductive requirements of amphibians. It is worth highlighting that Santa Teresa is one of the most sampled regions for amphibians in the Atlantic Forest (Rödder et al. 2007, Almeida et al. 2011, Zocca et al. 2014, Ferreira et al. 2016). About 3,800 anuran specimens collected in Santa Teresa were found housed in Brazilian collections (ET Silva, pers. obs.). This high sampling effort, which is comparable to only a few localities in the Atlantic Forest, may also account for such high species richness.

Conservation remarks

Amphibians from Santa Teresa have faced several anthropogenic disturbances over the last couple of decades. The first report on amphibian declines for Santa Teresa was in 1989 (see Weygoldt 1989). During long-term sporadic samplings (i.e., 1975 and 1988), Weygoldt (1989) reported the decline and possible disappearances of eight species (updated taxonomy: *Allobates capixaba*, *Crossodactylus* aff. *gaudichaudii*, *C. timbuhy*, *Cycloramphus fuliginosus*, *Hylodes lateristrigatus*, *H.* cf. *babax*, *Phasmahyla exilis*, and *Vitreorana* aff. *eurygnatha*). To our knowledge, *Cycloramphus fuliginosus* and *Hylodes* cf. *babax* have not been recorded after Weygoldt (1989). Additionally, *Thoropa petropolitana*, a frog not mentioned by Weygoldt (1989) has disappeared with no recent records along its entire range (Haddad et al. 2016). Several potential causes of these declines were mentioned by Weygoldt (1989), such as pollution (acid rain and pesticides), long-term climatic changes, and epidemic diseases. Weygoldt (1986) mentioned that *Crossodactylus* cf. *dispar* (currently *C. timbuhy*) was rare in Santa Teresa and later reported its decline. However, during our surveys we easily found this species on creeks across Santa Teresa. We cannot assess whether species declines are actually happening in Santa Teresa because only long-term and species-specific studies can precisely understand population trends.

Over the decades, we have noted population disappearances of anurans in Santa Teresa. The construction of condominiums and vacation ranches has intensified over the last decade and consequently increased deforestation of primary forest. We have also observed the expansion of the non-native *Eucalyptus* spp. plantations near primary and secondary forests and the replacement of coffee plantations. Another unmeasured concern is the increasing record of morphological anuran deformities, which is likely a result of pesticides used on crops (e.g., Mônico et al. 2016), including inside the buffer zone of the largest forest reserve (i.e., Reserva Biológica Augusto Ruschi; pers. obs.). The report of the invasive frog, *Lithobates catesbeianus*, in Santa Teresa (see Ferreira and Lima 2012) should be further evaluated to monitor its establishment, and possible spread and impacts. We emphasize the need to sample the surroundings of the nearby breeding farms of *L. catesbeianus*. Studies have shown that non-native *L. catesbeianus* can be voracious predators of native anurans and vectors of diseases (Schloegel et al. 2010, Silva et al. 2011, Boelter et al. 2012).

The landscape configuration of Santa Teresa does not safeguard the maintenance of amphibian reproduction outside protected reserves because forests on private properties are mostly restricted to hilltops and non-natural matrix habitats occupy most valleys. Because water-body breeding species migrate toward reproductive habitats in the valleys, these species face severe threats, such as the risk of predation and desiccation (Becker et al. 2007, Ferreira et al. 2016). In addition, pollution of creeks and streams further strengthen conservation concern of lotic body breeders. We reinforce the need of studies focused on the threats amphibians are facing in the region to provide knowledge for conservationists and reserves managers to safeguard the local diversity.

Santa Teresa is an important hotspot for amphibian conservation due to its high richness and number of endemic species. The discovery of several new species further emphasizes the importance of this mountainous region for amphibian conservation. Even though Santa Teresa and its surrounding areas in southeastern Brazil are one of the most sampled regions in the Atlantic Forest, the region still harbors numerous remote areas that have not yet been sampled for frogs (e.g., Almeida et al. 2011). Forests on private properties are also important for preserving amphibian diversity in the area (Ferreira et al. 2016). In addition, private properties may function as forest corridors for dispersing and migrating species. We suggest that a program to stimulate the creation of private-owner reserves and ecotourism activities should be implemented in this region. Finally, we have been developing outreach activities (e.g., Bromeligenous Project) with the local farmers, aiming to minimize the anthropogenic effects on anurans. Nevertheless, there is a strong need for a long-term outreach program in the local schools and in the farmlands to protect these forest areas in the future.

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Appendix I

Vouchers of examined specimens

Adelophryne glandulata (MBML 9560), *Allobates capixaba* (MZUSP 53559), *Aplastodiscus cavicola* (MBML 9620), *Aplastodiscus* aff. *eugenioi* (MBML 7901), *Aplastodiscus weygoldti* (MBML 9540), *Boana albomarginata* (MBML 9610), *Boana albopunctata* (MBML 9673), *Boana crepitans* (MBML 9624), *Boana faber* (MBML 9576), *Boana pardalis* (MBML 9577), *Boana semilineata* (MBML 9554), *Bokermannohyla caramaschii* (MBML 9552), *Brachycephalus alipioi* (MNRJ 25405), *Ceratophrys aurita* (MBML 591), *Chiasmocleis capixaba* (MBML 2644), *Chiasmocleis schubarti* (MBML 9599), *Crossodactylodes bokermanni* (MBML 3984), *Crossodactylodes izecksohni* (MBML 768), *Crossodactylus* aff. *gaudichaudii* (MBML 15), *Crossodactylus timbuihy* (MBML 13), *Cycloramphus fuliginosus* (USNM 200441), *Dendrophryniscus carvalhoi* (MBML 8722), *Dendropsophus berthaltutzae* (MBML 8589), *Dendropsophus bipunctatus* (MBML 2446), *Dendropsophus branneri* (MBML 9611), *Dendropsophus bromeliaceus* (MBML 7712), *Dendropsophus decipiens* (MBML 9590), *Dendropsophus elegans* (MBML 9543), *Dendropsophus giesleri* (MBML 8795), *Dendropsophus haddadi* (MBML 8775), *Dendropsophus microps* (MNRJ 30445), *Dendropsophus minutus* (MBML 9593), *Dendropsophus ruschii* (CFBH 37010), *Dendropsophus seniculus* (MBML 9591), *Euparkerella tridactyla* (MBML 7585), *Fritziana* aff. *fissilis* (MBML 46), *Fritziana tonimi* (MBML 8604), *Gastrotheca albolineata* (MBML 47), *Gastrotheca megacephala* (MBML 9672), *Haddadus binotatus* (MBML 9621), *Hylodes* cf. *babax* (USNM 222553), *Hylodes lateristrigatus* (MBML 9595), *Ischnocnema abdita* (MBML 1143), *Ischnocnema colibri* (MBML 10568-10572), *Ischnocnema* aff. *guentheri* (MBML 4534), *Ischnocnema* cf. *nasuta* (MBML 4667), *Ischnocnema oea* (MBML 8705), *Ischnocnema* aff. *parva* sp. 1 (MBML 9550), *Ischnocnema verrucosa* (MBML 9569), *Itapotihyla langsdorffii* (MBML 8585), *Leptodactylus cupreus* (MBML 6845), *Leptodactylus fuscus* (MBML 6003), *Leptodactylus* aff. *latrans* (MBML 2077), *Leptodactylus* aff. *spixi* (MBML 2439), *Macrogenioglottus alipioi* (MBML 93), *Myersiella microps* (MBML 9561), *Ololygon arduous* (MBML

9657), *Ololygon argyreornata* (MBML 2828), *Ololygon* cf. *flavoguttata* (MBML 9649), *Ololygon heyeri* (MBML 8581), *Ololygon kautskyi* (MBML 9594), *Phasmahyla exilis* (MNRJ 4120), *Phrynomedusa marginata* (MNRJ 46881), *Phyllodytes luteolus* (MBML 6785), *Phyllodytes* aff. *luteolus* (MBML 9658), *Phyllomedusa burmeisteri* (MBML 9581), *Physalaemus crombiei* (MBML 9542), *Physalaemus cuvieri* (MBML 9579), *Physalaemus maculiventris* (MBML 9567), *Physalaemus* cf. *olfersii* (MBML 2803), *Pipa* aff. *carvalhoi* (MBML 4519), *Pithecopus* aff. *rohdei* (MBML 9580), *Proceratophrys boiei* (MBML 142), *Proceratophrys laticeps* (MBML 3905), *Proceratophrys moehringi* (MBML 6409), *Proceratophrys paviotii* (MBML 9585), *Proceratophrys phyllostomus* (MBML 325), *Proceratophrys schirchi* (MBML 9677), *Rhinella crucifer* (MBML 9575), *Rhinella granulosa* (MBML 2573), *Rhinella diptycha* (MBML 687), *Scinax alter* (MBML 9612), *Scinax cuspidatus* (MBML 3594), *Scinax eurydice* (MBML 1128), *Scinax fuscovarius* (MBML 7820), *Scinax hayii* (MBML 4707), *Scinax* aff. *perereca* (MBML 508), *Scinax* cf. *x-signatus* (MBML 4542), *Siphonops annulatus* (MBML 8586), *Siphonops hardyi* (MBML 8909), *Thoropa* aff. *lutzi* (MNRJ 1373), *Thoropa miliaris* (MBML 9571), *Thoropa petropolitana* (MZUSP 27725), *Trachycephalus mesophaeus* (MBML 8793), *Trachycephalus nigromaculatus* (MBML 9213), *Vitreorana* aff. *eurygnatha* (MBML 9678), *Vitreorana uranoscopa* (MBML 3725), *Zachaenus carvalhoi* (MNRJ 84116).